Recasting LHC analyses with MADANALYSIS 5

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Outline

1. MADANALYSIS 5 in a nutshell

2. Reinterpretation of LHC analyses with MADANALYSIS 5 and DELPHES

3. The PAD (public analysis database) and examples

4. Summary

Monte Carlo tools and discoveries at the LHC

Exploration

There is some new physics to be discovered

A new physics LHC story

✦ *A priori* preparation
  - ✤ Model building
  - ✤ Phenomenological studies
  - ✤ Prospective collider analyses

✦ *A posteriori* reactions to announcements
  - ✤ Model building
  - ✤ Recasting experimental analyses
  - ✤ Measurements (precision predictions)

⇒ Monte Carlo tools play a key role!

⇒ **How to easily analyze their output?**

MADANALYSIS 5 in a nutshell (1)

✦ **What is MADANALYSIS 5?**
- ✤ A framework for phenomenological analyses
- ✤ Any level of sophistication: partonic, hadronic, detector, reconstructed
- ✤ Several input format: STDHEP, HEPMC, LHE, LHCO, ROOT (from DELPHES)
- ✤ User-friendly, flexible and fast
- ✤ Interfaces to other HEP packages (fast detector simulation, jet clustering, *etc.*)

✦ **Two modules**
- ✤ A PYTHON command line interface (interactive)
- ✤ A C++/ROOT core module, SAMPLEANALYZER

MADANALYSIS 5 in a nutshell (2)

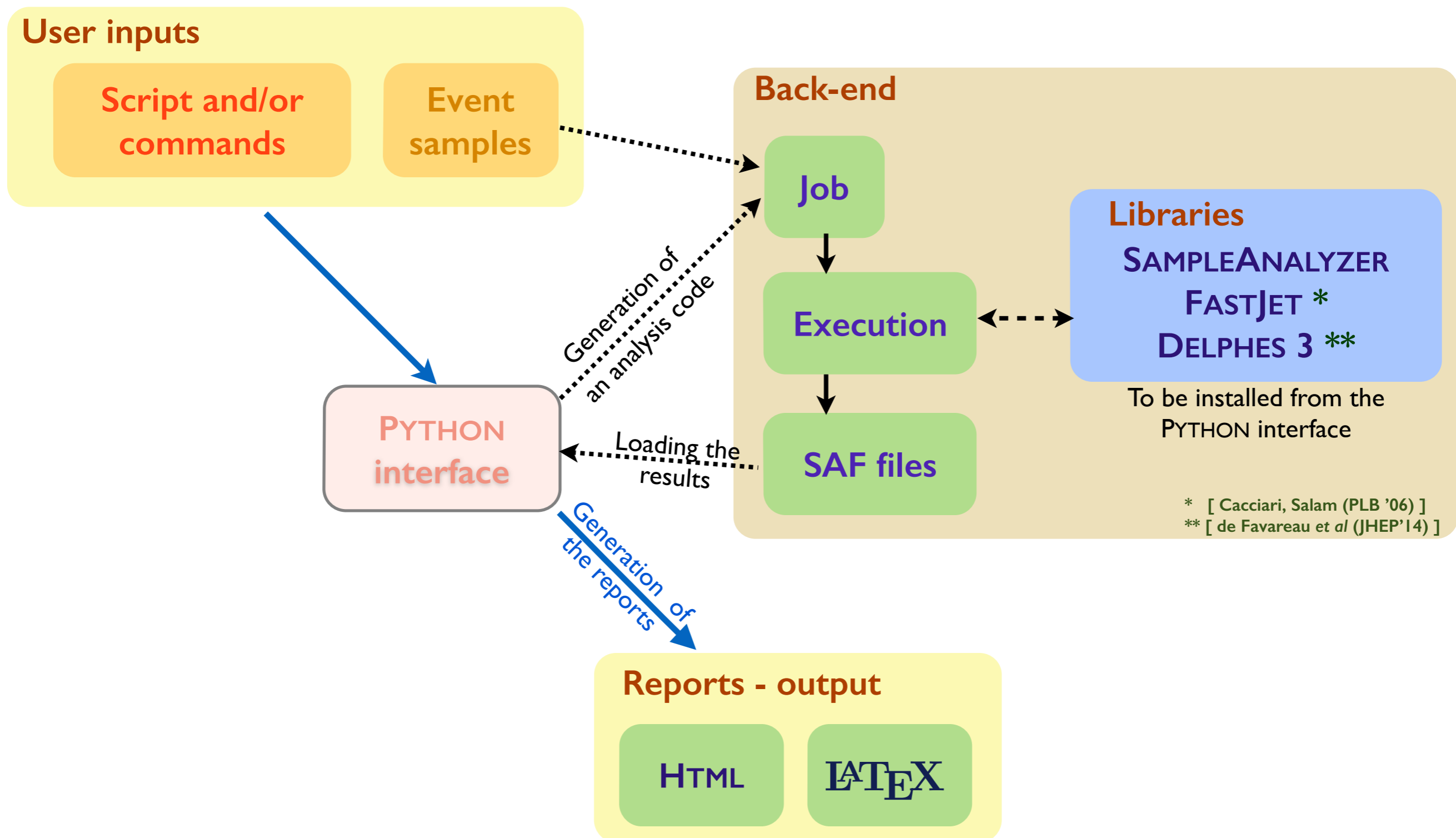[Conte, BF, Serret (CPC '13); Conte, Dumont, BF, Wymant (EPJC '14)]

✦ **Normal mode**
- ❖ Intuitive commands typed in the PYTHON interface
- ❖ Analysis performed behind the scenes (black box)
- ❖ Human readable output: HTML and $\LaTeX$

✦ **Expert mode: recently extended for recasting existing LHC analyses**
- ❖ C++/ROOT programming within the SAMPLEANALYZER framework
- ❖ Support for multiple sub-analyses, an efficient way for handling cuts and histograms, *etc.*

MADANALYSIS 5: normal mode

[Conte, BF, Serret (CPC '13); Conte, Dumont, BF, Wymant (EPJC '14)]

MADANALYSIS 5: expert mode

User inputs

Event samples

Code skeleton to be generated from the PYTHON interface

Job

Execution

SAF files

Libraries

SAMPLEANALYZER
FASTJET *
DELPHES 3 **

To be installed from the PYTHON interface

* [Cacciari, Salam (PLB '06)]
** [de Favareau *et al* (JHEP'14)]

Reimplementing new physics LHC searches (1)

✦ **Many search channels are investigated by CMS and ATLAS**

   ❖ Limits set on popular new physics theories and/or simplified models

   ❖ There are plethora of new physics realizations that deserve to be studied

     ★ The simplified model approach is not sufficient (e.g., different topologies)

     ★ Need for implementations of LHC analyses in public tools

     ★ Need to rely on a public detector simulation

✦ **The MADANALYSIS 5 way**

   ❖ Use of the expert mode of the program as a framework

   ❖ Use of DELPHES 3 for detector simulation

Reimplementing new physics LHC searches (2)

✦ Validation of the reimplementations
- ❖ Built-in differences: DELPHES *versus* ATLAS and CMS detector simulations
- ❖ Comparison of cut-flows, kinematical distributions for specific benchmarks
- ❖ Aiming for a 20%-30% agreement

✦ Complications: incomplete experimental documentation
- ❖ The material is better and better
- ❖ Loss of months in exchanges with ATLAS and CMS
- ❖ Sometimes dead ends

Detector simulation with DELPHES and MADANALYSIS (1)

✦ **Fast detector simulation with MADANALYSIS 5**

♣ MADANALYSIS 5 has been interfaced to DELPHES 3

♣ Starts from events at the hadron level and produces ROOT files (DELPHES)

♣ DELPHES is modular ➢ MADANALYSIS 5 includes extra modules (DELPHES-MA5Tune)

★ Extra information on lepton isolation

★ Track information

★ Exported to the output file and in the analysis code

★ Smaller output ROOT files (DELPHES)

★ This version of DELPHES can be executed from MADANALYSIS 5

Detector simulation with DELPHES and MADANALYSIS (2)

[Dumont, BF, Kraml *et al.* (EPJC '15)]

✦ **Running DELPHES in MADANALYSIS 5**

♣ Running of DELPHES via the MADANALYSIS 5 interpreter (in the reco mode)

♣ Choice of ATLAS or CMS; pile-up can be included

♣ Different cards could be necessary for different analyses

♣ The ROOT output file is stored

✦ **Future developments**

♣ In collaboration with the CHECKMATE team (common analysis implementations)

♣ Use of the standard DELPHES with a DELPHES-recasting card

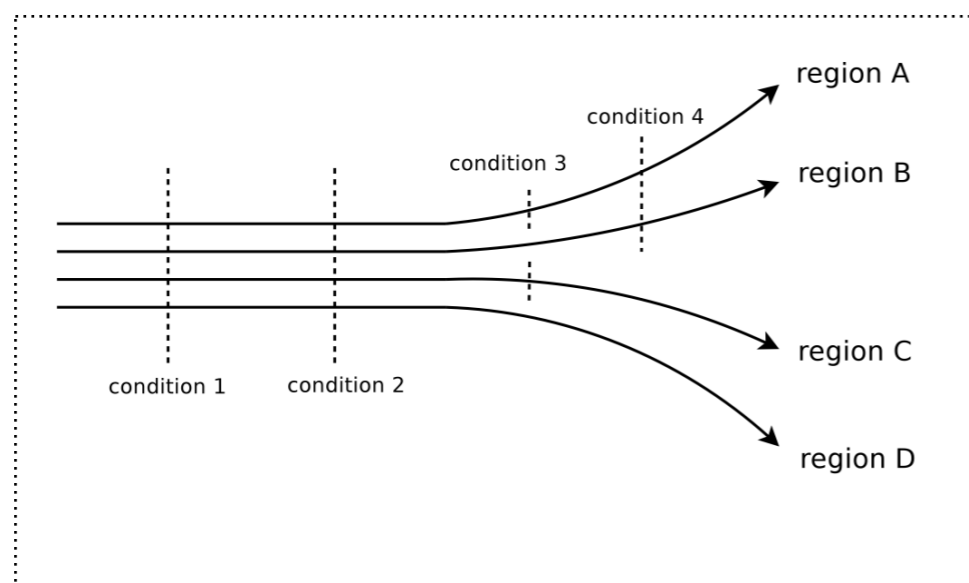# The expert mode of MADANALYSIS 5 (I)

✦ **Main features (enable an easy recast of cut-based LHC analyses)**
  ✤ Support for multiple sub-analyses (signal and control regions)
  ✤ New ready-to-use observables (M_{T2}, M_{T2W}, *etc.*)
  ✤ New optimized handling of cuts and histograms

✦ **Handling cuts and histograms**
  ✤ Naive approach not efficient (see cut #4 for instance)


```
count the event in region D
if (condition 3)
{
    count the event in region C
    if (condition 4)
    {
        count the event in region A
    }
}
if (condition 4)
{
    count the event in region B
}
```

  ✤ A more efficient algorithm has been implemented
    ★ Each cut condition is only evaluated once
    ★ It is applied to all <u>surviving</u> regions simultaneously
  ✤ Similar treatment for histograms

The expert mode of MADANALYSIS 5 (2)

[Conte, Dumont, BF, Wymant (EPJC '14)]

✦ **MADANALYSIS 5 is used without its PYTHON interface**
- ❖ More freedom in the observables (only some of them can be called from the PYTHON console)
- ❖ Complicated cuts can be implemented
- ❖ More suitable for large numbers of events (using several cores)

✦ **The expert mode is developer-friendly**

The analysis is a C++ class

The SAMPLEANALYZER internal data format

- ★ Readers for LHE, STDHEP, HEPMC, LHCO and DELPHES
- ★ Many classes and methods for particle and object properties
- ★ Specific methods for histograms and cuts
- ★ etc.

Services

- ★ Physics observables (transverse variables, object identification, isolation)
- ★ Streamers
- ★ Exceptions
- ★ etc.

Interfaces

- ★ FASTJET
- ★ DELPHES 3
- ★ New DELPHES modules

The new DELPHES modules (linked to SAMPLEANALYZER):
- ★ isolation
- ★ tracks
- ★ output files

Scripts

- ★ Compilation
- ★ Linking
- ★ Analysis skeleton generator

The Physics Analysis Database (PAD) of MADANALYSIS

[Dumont, BF, Kraml *et al.* (EPJC '15)]

✦ **A database with MADANALYSIS 5 implementations of LHC analyses has been initiated**

♣ http://madanalysis.irmp.ucl.ac.be/wiki/PhysicsAnalysisDatabase

♣ Easy to install (*install PAD*)

♣ Seven analyses are public and validated

ATLAS analyses, 8 TeV

Analysis	Short Description	Implemented by	Code	Validation note	Status
➥ATLAS-SUSY-2013-05 (published)	stop/sbottom search: 0 leptons + 2 b-jets	G. Chalons	➥Inspire	➥PDF ➥(figures)	done
➥ATLAS-SUSY-2013-11 (published)	EWK-inos, 2 leptons + MET	B. Dumont	➥Inspire	➥PDF ➥(source)	done
➥ATLAS-HIGG-2013-03 (published)	ZH->ll+invisible	B. Dumont	➥Inspire	➥PDF ➥(source)	done
➥ATLAS-EXOT-2014-06 (published)	mono-photons + MET	D. Barducci	➥Inspire	➥PDF	done

➥ Delphes card for ATLAS-SUSY-2013-05
➥ Delphes card for ATLAS-SUSY-2013-11

DELPHES cards

Code from INSPIRE

Validation notes
(cutflows, distributions, *etc.*)

CMS analyses, 8 TeV

Analysis	Short Description	Implemented by	Code	Validation note	Status
➥CMS-SUS-13-011 (published)	stop search in the single lepton mode	B. Dumont, B. Fuks, C. Wymant	➥Inspire [1]	➥PDF ➥(source)	done
➥CMS-SUS-13-012 (published)	gluino/squark search in jet multiplicity and missing energy	S. Bein, D. Sengupta	➥Inspire	➥PDF ➥(source)	done
➥CMS-SUS-13-016 (PAS)	search for gluinos using OS dileptons and b-jets	D. Sengupta, S. Kulkarni	➥Inspire	➥PDF ➥(source)	done

➥ Delphes card for these analyses

DELPHES cards

MADANALYSIS 5 analyses on INSPIRE

[Dumont, BF, Kraml *et al.* (EPJC '15)]

✦ Implementation of LHC analyses can be uploaded on INSPIRE
  ❖ DOI are assigned: can be cited, searched for, *etc.*

Information   Citations (3)   Files   →   Files are versioned, can be downloaded

MadAnalysis 5 implementation of CMS-SUS-13-011: search for stops in the single lepton final state at 8 TeV

DOI and citations

Dumont, Beranger (LPSC, Grenoble); Fuks, Benjamin (CERN); Wymant, Chris (Annecy, LAPTH)

Cite as: (2014) authors, http://doi.org/10.7484/INSPIREHEP.DATA.LR5T.2RR3

Description: This is the MadAnalysis 5 implementation of the CMS search for top-squark pair production in the single lepton final state with 19.5/fb at 8 TeV, to be used for re-interpretation studies. The C++ code contains extensive comments and can thus easily be used as a template for implementing other analyses.

Note: This analysis requires MINUIT libraries. Therefore, the line <LIBFLAGS += -lMinuit> should be added to the Makefile of the Build/ directory before compilation. More information how to use this code as well as a detailed validation summary are available at http://madanalysis.irmp.ucl.ac.be/wiki/PhysicsAnalysisDatabase

Cite as: Dumont, B., Fuks, B., Wymant, C. (2014) MadAnalysis 5 implementation of CMS-SUS-13-011: search for stops in the single lepton final state at 8 TeV. doi: 10.7484/INSPIREHEP.DATA.LR5T.2RR3

This dataset complements the following publication:
Toward a public analysis database for LHC new physics searches using MADANALYSIS 5

Record added 2014-06-19, last modified 2014-07-17

CMS-SUS-13-011

✦ **CMS search for stops in the single lepton channel**

❖ Benchmark: stop of 650 GeV and neutralino of 50 GeV

✦ **Validation with public material from CMS**

| Cut	MADANALYSIS 5	CMS
At least one lepton, four jets and 100 GeV of missing transverse energy	31.4	29.7
At least one b-tagged jet	27.1	25.2
No extra loosely-isolated lepton or track	22.5	21.0
No hadronic tau	22.0	20.6
Angular separation between the missing momentum and the two hardest jets	18.9	17.8
Hadronic top quark reconstruction	12.7	11.9
The transverse mass M_T (defined in the text) is larger than 120 GeV	10.4	9.6
At least 300 GeV of missing transverse energy and $M_{T2}^W > 200$ GeV	5.1	4.2
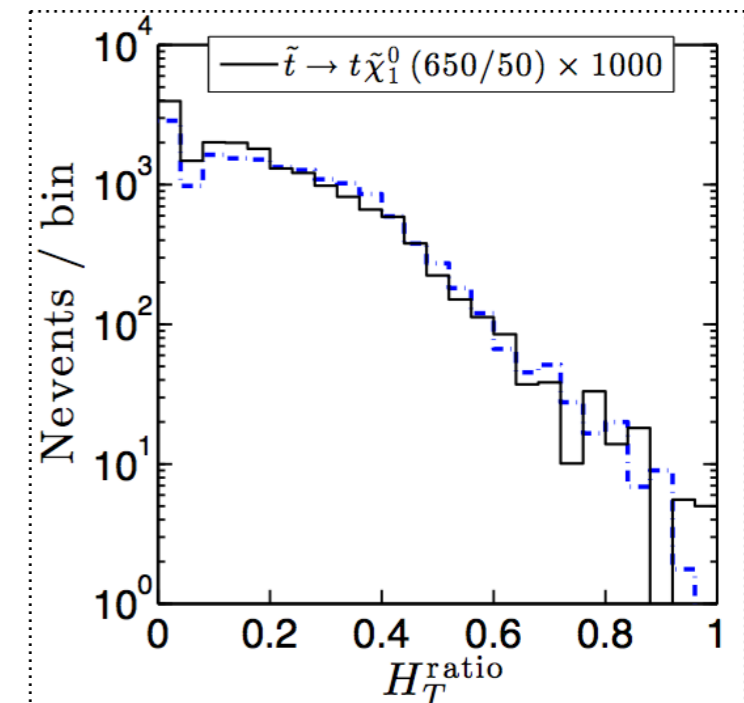
CMS results can be reproduced at the 20%-30% level

ATLAS-SUS-2013-05

[Chalons (2014)]

✦ ATLAS search for stops and sbottoms in the <u>zero lepton plus 2 b-jets</u> channel
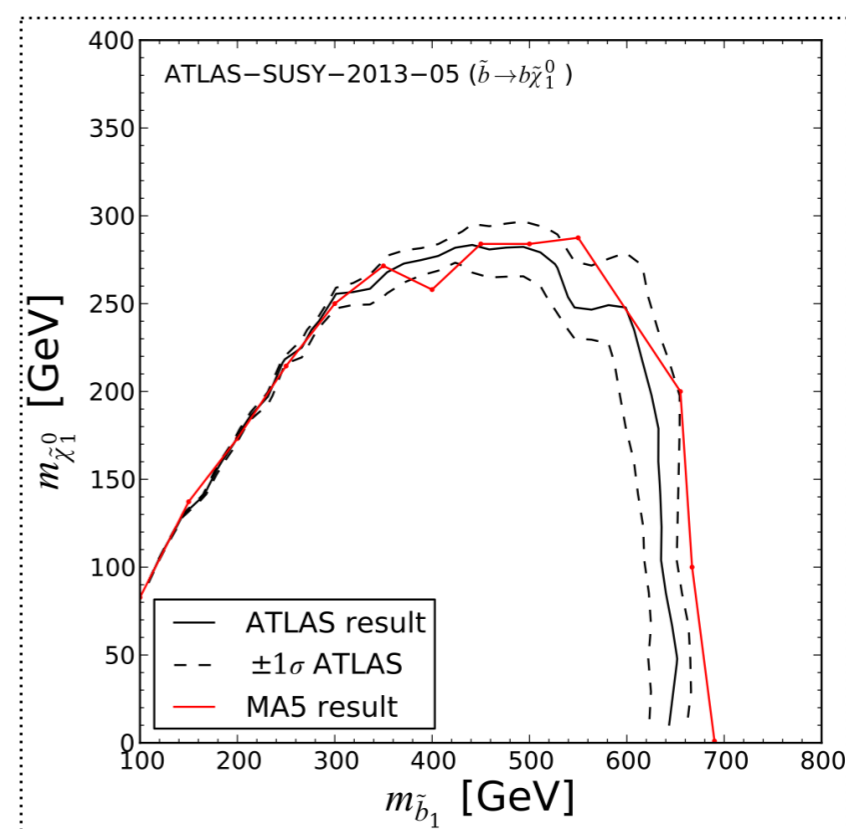   ❖ Benchmarks: sbottom/neutralino (300/200 GeV) and stop/chargino/neutralino (250/155/50 GeV)

✦ Validation with public ATLAS material
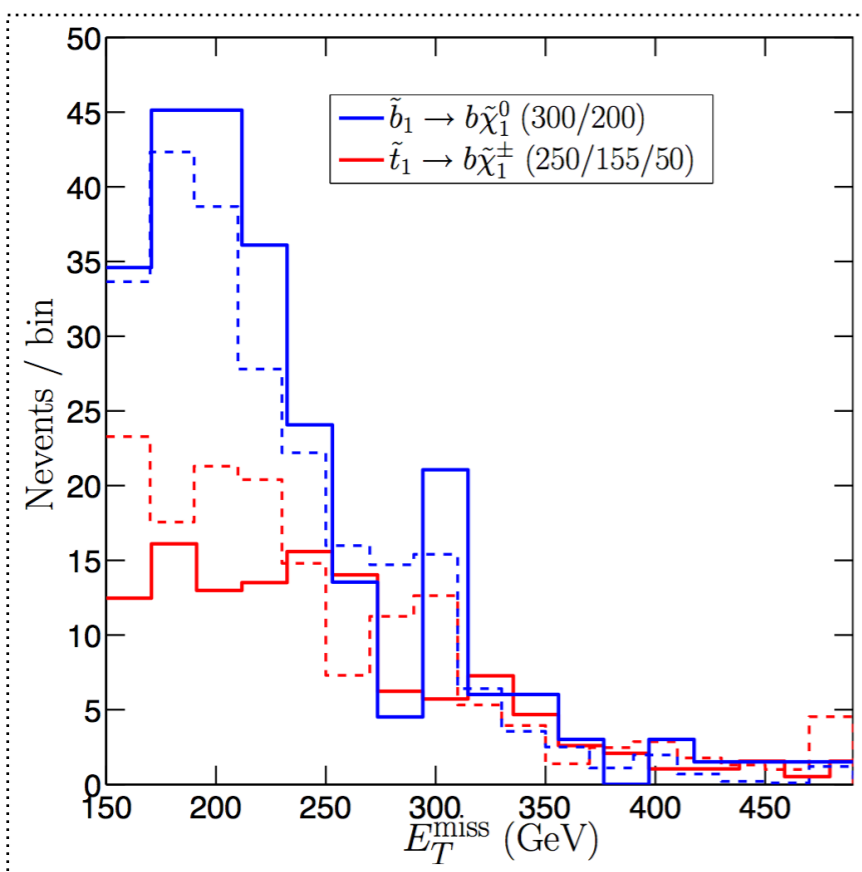
ATLAS limits can be reproduced at the 50 GeV level

✦ Setting limits
     ❖ CLs: from observed and expected numbers
     ❖ Best expected signal region is employed
         ➢ Conservative

Reinterpretation and constraining new physics

[Belanger, Dumont, Goudelis, Herrmann, Kraml, Sengupta (2015)]

✦ ATLAS searches in dilepton + missing energy channel
  ♣ ATLAS-SUSY-2013-11: chargino, neutralino and slepton searches [10.7484/INSPIREHEP.DATA.HLMR.T56W.2]
  ♣ ATLAS-HIGG-2013-03: Z (to two leptons) + H (invisible) [10.7484/INSPIREHEP.DATA.RT3V.9PJK]

✦ Constraining the inert doublet model
  ♣ One SM Higgs + non-mixing extra scalars
  ♣ The dilepton + missing energy probe

$$q\bar{q} \to Z \to A^0 H^0 \to Z^{(*)} H^0 H^0 \to \ell^+\ell^- H^0 H^0,$$
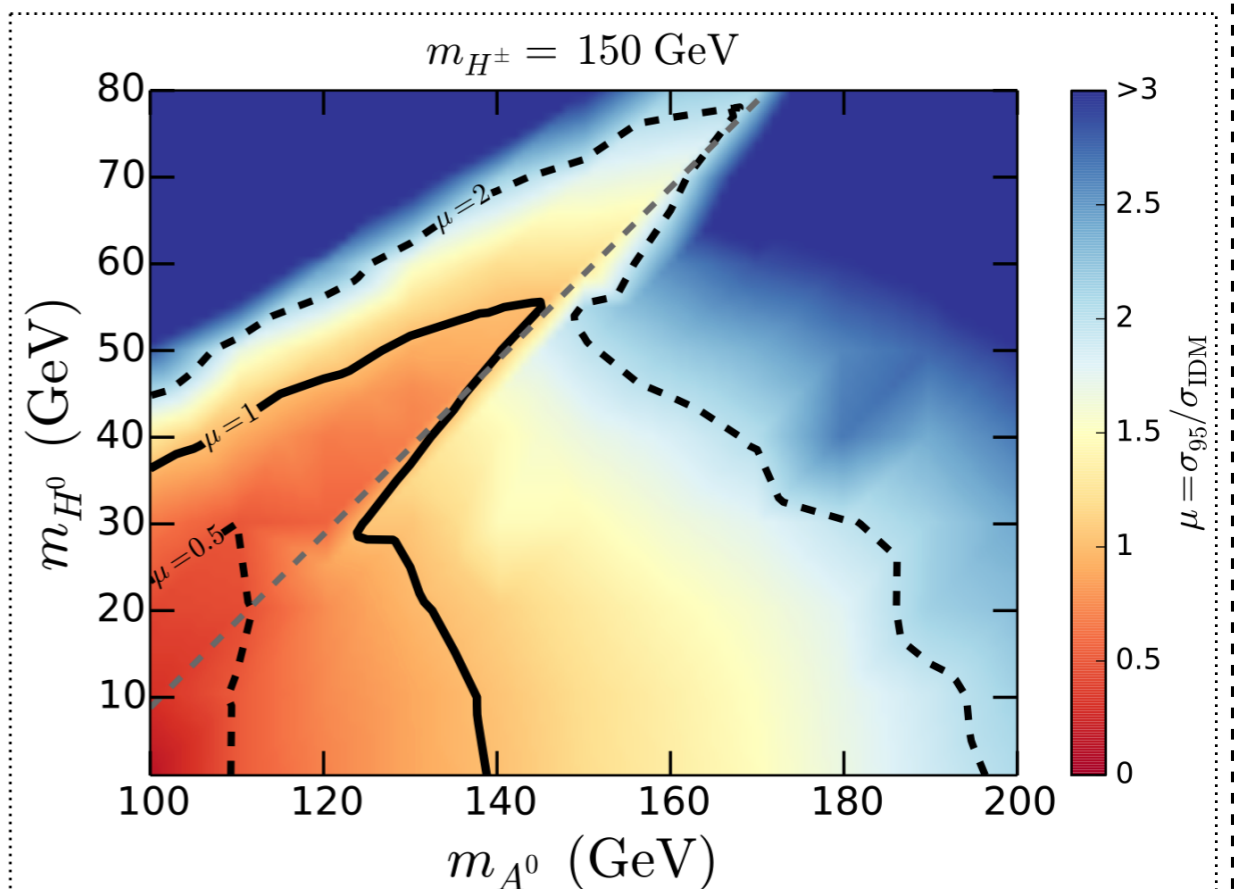$$q\bar{q} \to Z \to H^{\pm} H^{\mp} \to W^{\pm(*)} H^0 W^{\mp(*)} H^0$$
$$\to \nu\ell^+ H^0 \nu\ell^- H^0,$$
$$q\bar{q} \to Z \to Zh^{(*)} \to \ell^+\ell^- H^0 H^0,$$
$$q\bar{q} \to Z \to Z H^0 H^0 \to \ell^+\ell^- H^0 H^0.$$

✦ Constraints in the model parameter space
  ♣ Regions with $\mu < 1$ are excluded (95% CL)

Summary

✦ **MADANALYSIS 5 in a nutshell**
- ✤ A unique framework for collider phenomenology at all levels (parton, hadron, reconstructed)
- ✤ User-friendly by means of its PYTHON interface (normal mode)
- ✤ Flexible thanks to its C++ kernel (expert mode)
- ✤ Interfaced to several other HEP packages (DELPHES, FASTJET)

✦ **MADANALYSIS 5 and LHC analyses**
- ✤ The expert mode has been extended to facilitate the implementation of LHC analyses
- ✤ Seven analyses are validated and public
  - ➢ ATLAS and CMS results are recovered at the 20-30% level
- ✤ O(20) analyses are being validated (*i.e.*, will become public soon)
- ✤ An interface with CHECKMATE is being developed

✦ **Please use and contribute to the database**
- ✤ http://launchpad.net/madanalysis5
- ✤ http://madanalysis.irmp.ucl.ac.be/wiki/PhysicsAnalysisDatabase